BULLHEADING II TWO PHASE SIMULATION OF A DEFINITIVE WELL KILL

By

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Dissertation submitted in partial fulfillment

of the requirements of the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2013

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CERTIFICATION OF APPROVAL

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Approved:

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Final Year Project Supervisor

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November 2013

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Moshey Arens William

ACKNOWLEDGEMENT

Given this opportunity, I would like to acknowledge those who have been helping me, either directly or indirectly, in continue working on the project – starting from preliminary research, to the development phase and until the completion phase of this Final Year Project in Universiti Teknologi PETRONAS.

I would like to thank Dr. William Pao, my supervisor for this project for the past two semesters. Dr. Pao has been giving me moral and mental support since the first. His understanding and confidence on my capabilities and passion towards the idea has given me the flexibility and spiritual advantages that I needed in conducting the project from the start to finish.

Besides that, I also like to thank seniors and colleagues in the university for their assistants in helping me to master visual basic for application skills needed during developing program as a prototype of this project. The same gratitude goes to my beloved parents for always giving me advice and support that has boosted my confidence in exploring further into the project.

ABSTRACT

Bullheading refers to the pumping or squeezing of fluids into the well against pressure in order to force back the escaped gas into the formation in order to kill the well. However, the main concern in bullheading is that when the gas leaks and goes up to the surface, it may have the potential to cause a blowout. It is common in well killing method but little written information is available in this area. The aim of this research is to determine the factors affecting bullheading through parametric studies. This study is will be focusing on vertical well with five well control parameters which are the killing fluid pressure, velocity, viscosity ration and friction wall of tubing in analyzing the volume fraction of water and pressure drop in the tubing. In the methodology, a base case model is selected which is the internal diameter and length of tubing are 4in and 50in respectively. The simulation will be using two fluids which are fresh water as the killing fluid and natural gas as the escaped gas. Based on the parametric study, the most contributing factors to volume fraction of water are the velocity of killing fluid followed by viscosity ratio. While, pressure of killing fluid and the friction wall of tubing contributes less in volume fraction of water. However, looking in term of pressure drop, viscosity ratio has the highest contribution factor followed by velocity of the killing fluid whereas pressure of killing fluid has the least effect. In conclusion, the four factors shows individual effects on bullheading which will assist in successful well kill.

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ABBREVIATIONS AND NOMENCLATURES

ABBREVIATIONS

FYP	Final Year Project
VOF	Volume of Fluid
CFD	Computational Fluid Dynamic

NOMENCLATURES

$\vec{v}$	Velocity
α	Volume fraction,
ρ	Density
p	Pressure shared by all phases
$\vec{v}_{qp}$	Inter-phase velocity
$\vec{g}$	Gravitational acceleration
$\vec{F}_q$	External body force
$\vec{F}_{lift,q}$	Lift force
$\vec{F}_{vm,q}$	Virtual mass force,
$\vec{R}_{pq}$	Interaction force between phases

$\dot{m}_{pq}$	Mass transfer from p$^{\text{th}}$ to q$^{\text{th}}$ phase
L	Length of Tubing (in)
ID	Internal Diameter of Tubing (in)
υ_r	Viscosity Ratio
μ_w	Friction Wall
P_w	Water Pressure (MPa)
υ_w	Water Velocity (m/s)
υ_w	Viscosity of Water (kg/m-s)
ρ_w	Density of Water (kg/m^3)
P_g	Gas Pressure (MPa)
υ_w	Gas Velocity (m/s)
υ_g	Viscosity of Gas (kg/m-s)
ρ_w	Density of Gas (kg/m^3)
t	Simulation Time (s)

CHAPTER 1

INTRODUCTION

1.1 Background Study

In well drilling, it is important that the formation fluids are kept from entering the wellbore. The process is known as well control in petroleum industry. Well control is initiated when there is a sign of well “kick”. A kick, if not detected or monitored, it may lead to blowout of well, which is an undesirable event. When a kick is detected, drilling crew will proceed to the well killing procedures in order to prevent the kick from reaching the surface. A column of heavy fluid is placed into the wellbore to suppress the pressure of formation fluid by using the weight of the kill-fluid.

Bullheading is said to be the simplest method in killing a gas filled wellbore. It is a process of pumping fluid into the formation, usually formation fluid that entered the wellbore during drilling. In the bullheading technique, the formation pressure is intentionally exceeded by the pumping of fluid from the surface down the well forcing the formation fluid back into the reservoir. During the operation, the well flowing pressure must increase when liquid is pumped in at the top at a constant rate and driving the gas back into the formation. This is due to the constant compression of the wellbore and harder to leak-off time since the reservoir pressure increases. Well flowing pressure is depending on the surface pump-pressure and hydrostatic pressure at the wellbore. The pressure during the operations must not exceed the formation breakdown pressure or the tubing burst pressure. Head effect of the liquid decreases the wellhead pressure as the water fills the tubing.

This method is the most unstable displacement due to the fact it is on top of a gas column since the common kill fluid is used is water. Gas bubbles will rise through the liquid if the pumping stops at any point before the well kill which lead to a blowout of well. Bullheading must be monitored all the time in order to avoid any disturbances during in the operation during well killing to ensure that the process is in a safe manner.

1.2 Problem Statement

Bullheading operation in oil and gas industry is considered one of the risky jobs in well control. The major risk is that the fluid circulation along the tubing cannot be control and usually the fluid being pumped down hole enters the weakest formation. Furthermore, wellbore fluids will broach around the casing shoe and reach the surface when a shallow casing is cemented into the well. The fluids are known as the formation fluids. If the formation fluid reaches the surface, it may have potential to cause blowout of the well. The broaching of the fluid has the effect of fluidizing and destabilizing the soil which results in the formation of crater and loss of the equipment life.

1.3 Objectives

The objective of this research is:

i. To develop and simulate a two-phase bullheading model in different well control parameters which is killing fluid pressure, velocity, viscosity ratio and friction wall of tubing.

ii. To investigate on the well parameters trough parametric study to determine the contributing factors affecting bullheading by analyzing the volume fraction of water and pressure drop in tubing.

1.4 Scope of Study

This research focuses on the analysis of two phase bullheading along vertical tubing. The two fluids apply in the tubing which is fresh water as the killing fluid and natural gas act as escape gas from the formation. There are four parameters prioritize to be examine in this study which is killing fluid pressure, velocity, viscosity ratio and friction wall of tubing.

1.5 Significance of Study

There is not much written information in this area that is related to factors affecting bullheading. In this research, the factors can be obtained and determined through parametric studies base on the four well control parameters and condition. This will assist in optimizing bullheading operation by knowing the factors. Therefore, this will prevent the gas from leaks which have the potential of causing blowout.

1.6 Outline of Thesis

Appropriate analysis is required to investigate the factor affecting bullheading operation. The contributions of present study for this report are presented in four chapters. An overview of each chapter is given below.

Chapter one introduced bullheading, problem statement, objectives, scope of study and significance of study.

Chapter two presents the review of the available studies and theory related to Bullheading operation.

Chapter three presents the methodology used for bullheading model simulation. The assumptions, mathematical formulation and boundary conditions are discussed in detail in this chapter.

Chapter four show the expected results for this study. While, chapter five draws conclusion and makes recommendation from the analysis conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 Modeling of Bullheading

The bullheading model is designed based on two models. The first model is known as "Non-Slip Theory", where the displacement of gas in the tubing such that piston-like displacement. The second model is the "Slip Theory" where multi-phase flow of fluid is exists. The required parameters for bullheading will be intergrated with the two models for simulation of the bullheading

2.1.1 The Non-Slip Theory

This model is also known as the simple bullheading model. The continuous loss of kill fluid into the reservoir is the main concern which needs to be monitored and controlled during the operation.

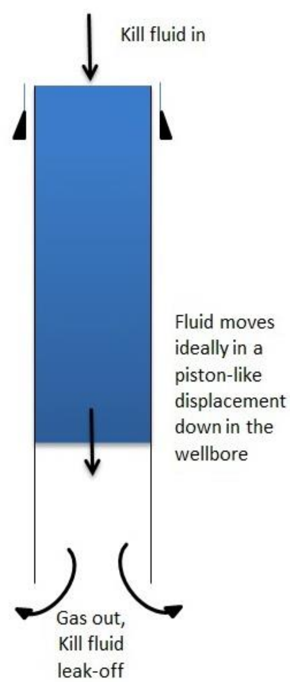


Figure 2.1 A Simple Bullheading Model with Non-Slip Theory (Grodal, 1993)

The most ideal bullhead kill is achieved in a no-situation as in Figure 1. No- slip bullheading model is just an assumption use in petroleum industry. However, it is used to analyze the injectivity of gas reservoir when the wellbore gas is displaced back into the formation. Based on the model, the transient pressures along the tubing and at wellface will be known when the reservoir gas is force back into the reservoir in a piston-like manner. The result is achieved by use of set of equations that are developed in gas well testing analysis.

2.1.2 The Slip Theory

Referring to Grodal E. O., slip theory is considered as a more realistic model due to fact of its complexity and little information related to two-phase down flow and the development of the transition zone. Before that, to analyze the model, the following simple assumptions are made:

a. Constant slip-velocity, between liquid and gas.

b. Constant average liquid fraction along the transition zone.

The slip velocity is the velocity of the carrying fluid relative to the moving solids that reflects the interaction between liquid and solid. It is a demonstration of the holdup phenomenon that exists in two-phase flow. The cross-section of the transition zone is the liquid fraction which is occupied by the kill fluid.

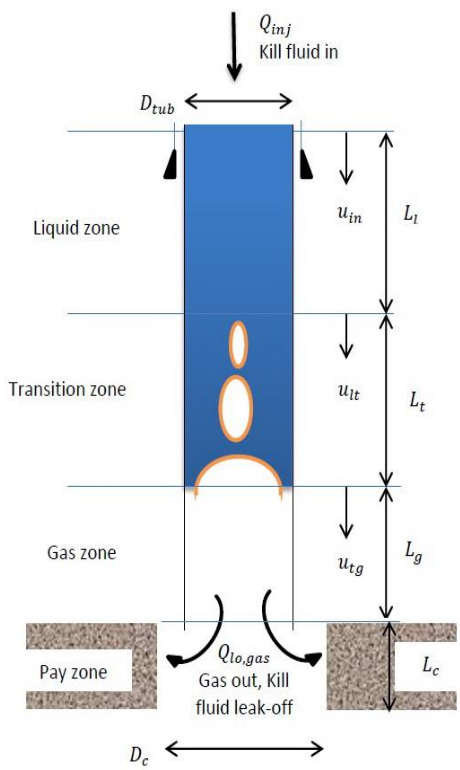


Figure 2.2 The three different zones in the wellbore during a Bullheading kill (Grodal, 1993)

The process of modeling a bullheading is just as Figure 2 where three zones in the tubing can be differentiate which is the liquid zone, transitional zone and gas zone. The explanation as below:

- ***Liquid zone***: It contains only kill-fluid where it will move downward until the sand face is reached. When the gas is swept from the well, therefore, the kill is completed.
- ***Transition zone***: Gas and liquid that has bypassed the gas and infiltrating up in the liquid zone. This zone will grow as more liquid bypassed, until the first liquid arrives at sand faces and start leaking off.
- ***Gas zone***: Contain gas during most time of the well kill. As the kill proceeds, the length of the zone slowly decreases.

2.2 Well Monitoring and Kick Detection

Kick is an undesirable flow of an unwanted influx or formation fluid or gas into the wellbore. The entering of influx into the reservoir due to the barrier (mud or cement) failed to control the fluid pressure in the formation. Basically, in order to control the kick, it must be detected by the drilling crew on the rig, then stop it from progressing by adding one or more barriers. The influx has to be circulated out from the wellbore. Failing on reacting properly to the condition, this will eventually escalate out into an uncontrolled flow from the well or in other word blowout of a well.

2.3 Causes of Well Kick

The main causes of kicks are:

a) Failing to fill the hole properly

b) Swabbing in a kick

c) Insufficient mud weight

d) Lost Circulation

2.3.1 Failing to fill the hole properly

This is one of the common causes of a well kick. According to Robert D.G, this phenomenon occurs when the fluid level in the hole falls causing a reduction of bottom hole pressure since the length of the fluid column has shortened. When a drill pipe is removed from the hole, a volume of mud equal to the volume of the steel which has been removed must be added to keep the hole occupied. If this is not done, the length of the mud column is reduced causing a reduction of bottom hole pressure. Once there is a pressure drop below formation pressure, at any point of the open hole, a kick may happen. The hole either must be filled in continuous-basis or with a recirculating tank.

2.3.2 Swabbing in a kick

After a drilling string is pulled up out of the hole during a trip, mud will flow down to fill the space left behind. Tripping is act of removing or running the drill string into the hole where some changes will be done such as the replacement of the damage drill bit (Weatherford, 2011) as shown in Figure 3. Energy is required to move the mud which causes the pressure drop in the hole. The effect is that the total pressure exerted by the fluid column is reduced slightly. Each time the drill string is moved, there will be a pressure variation.

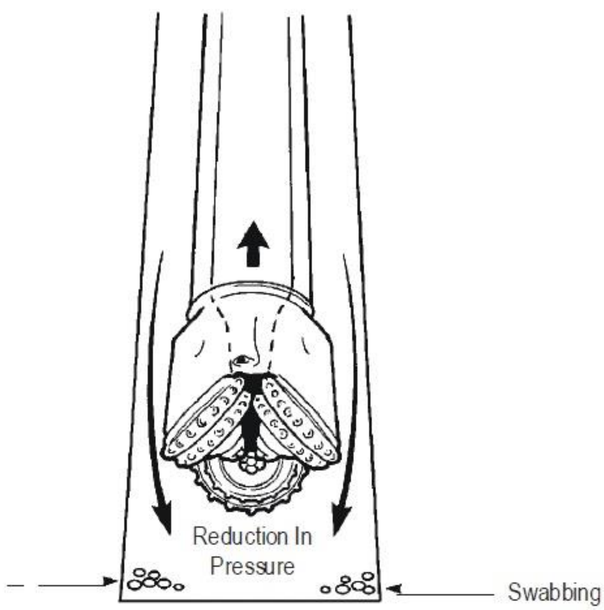


Figure 2.3 Swabbing Effect (Weatherford, 2011, p.43)

2.3.3 Insufficient mud weight

Hydrostatic pressure exerted by the column of the mud in the hole is the primary role in preventing kicks. At abnormal high-pressure zone, due to the insufficient mud weight may cause gas to penetrate unexpectedly due to imbalance of pressure during drilling (Robert D. G, 2003).

One of the main concerns is the dilution of the mud with the make-up water in the surface tanks which may result in reduction of mud weight.

2.3.4 Lost Circulation

Kick also occur when there is a loss of circulation during drilling and well control. The loss of circulation of the mud occurs due to the abnormal, naturally fractured and pressure depleted zone exist in the well (Weatherford, 2011) as in Figure 4. It also due to the applying of more mud pressure on the formation where it is not strong enough to withstand the pressure, hence causing an open hole fracture which allow the mud to flow. When this type of kick occurs, it may rapidly become very severe because it promotes the formation of large influx. A large influx may result in a huge blowout at the surface or underground.

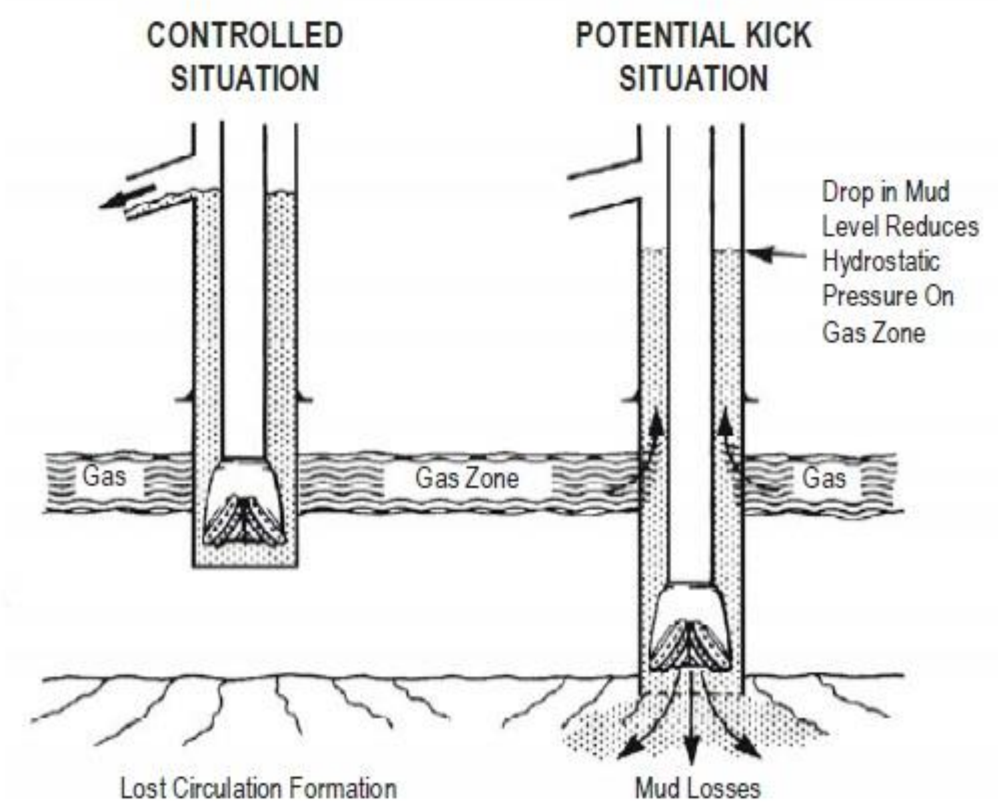


Figure 2.4: Typical situation for lost circulation of the mud (Weatherford, 2011, p.45)

2.4 Kick Indicators

There are number of warning signs and indications, which alert the presence of a kick, or an impending kick. The indications that a kick is in progress during drilling are:

- Flow rate increase
- Pit volume increase
- Pump pressure decrease/pump stroke increase
- Drilling Break

2.4.1 Flow Rate Increase

Robert D.G. stated that when an influx is flowing into a well with normal circulation in progress, the total volume of material flowing out of the well are also increases. The use of flow sensor such as flow paddle system provides means measuring quite small variations in flow Figure 5 shows the flow paddle system. When a kick is occurring from relatively low permeability formation, it is unlikely that any variation in flow rate will be observable. If it can be detected, this change in flow rate is a definite sign of kick in progress. There are few other possible causes for an increase in flow rate and usually that flow rate increase in the first reliable indicator of a kick in progress.

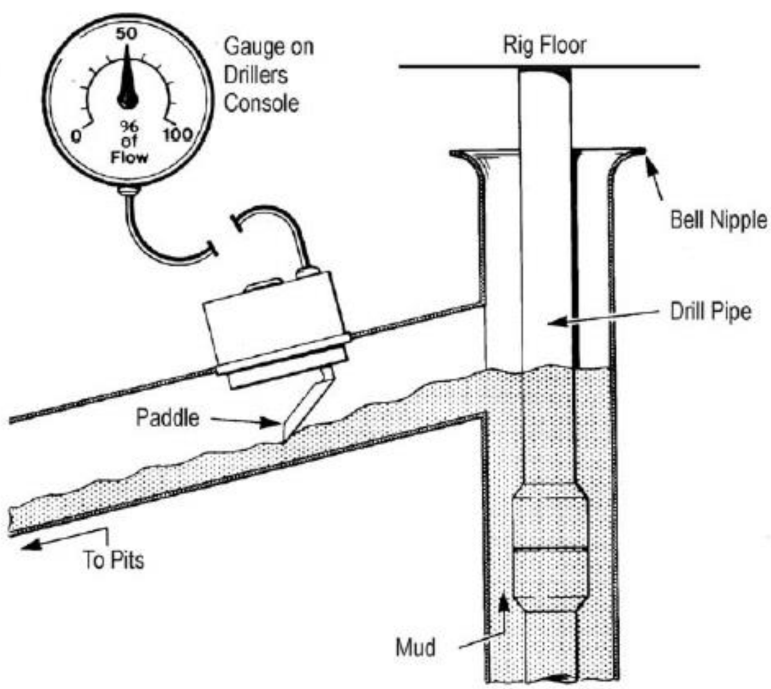


Figure 2.5 Flow Rate (Weatherford, 2011, p.51)

2.4.2 Pit Volume Increase

The invasion of formation fluid results from the expulsion of mud from the well causes an increase in surface volume normally in closed circulating system (Weatherford, 2011). As is the case with flow rate, a gain in pit level may be hard, or impossible, to detect when a slow bleed-in of fluid occurs. It is also easy for others to mask a change in pit level. Surface additions to the mud system, or surface withdrawals and dumping, must be done with Driller's knowledge. When a continuous addition is being made, the addition rate should be determined and monitored so that any further increase due to a kick can be detected. For instance, the addition of significant amounts of material such as barite also changes the total mud volume. This should be pre-calculated, and again the Driller's informed of the likely increase, and over what period such increase will occur.

2.4.3 Pump Pressure Decrease/ Pump Stroke Increase

Invading formation fluid generally reduces the total head of fluid in the annulus. The required energy that needs to be provided by the pump is lesser and this may see as a pump pressure reduction (Victor V.G, 2002). Depending on the rig installation, a small increase in pump rate may also be noted. The effect is small, and may not be noticeable. The same effects are seen if a washout occurs, so it is necessary to confirm which is taking place by doing a flow check. The presence of a continuous recording monitor of pump pressure and pump stroke rate on the drill floor means that quite small change can be seen readily by the Driller as shown in Figure 6.

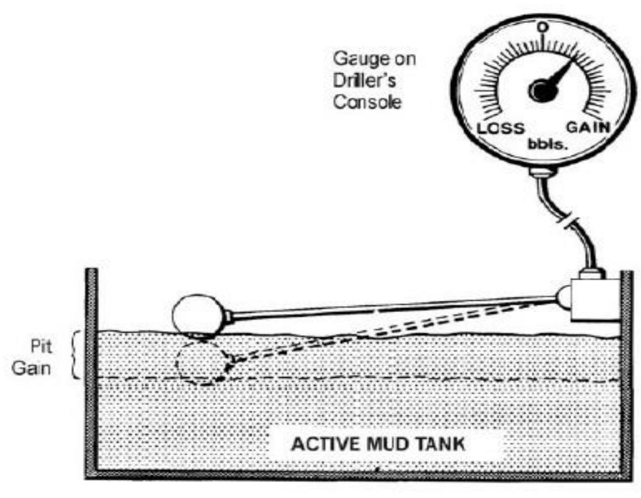


Figure 2.6 Reduction in pump pressure (Weatherford, 2011, p.54)

2.4.4 Drilling Break

A sudden increase in rate of penetration is usually caused by a change in formation type. It is a signal an increase in permeability and a loss of pressure overbalance (Chief Council Report, 2011). These effects results in faster drilling. The drilling break may be spectacular, though most commonly a gradual change is seen. It is rare for the drilling break to indicate a kick is in progress, though it is often a sign that conditions are changing and formation pressure rising which may lead to a kick.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

Figure 3.1 are the five phases in project methodology used to achieve the objective of the research. The first phase is the literature survey on the bullheading to determine the possible variables in this research. Next is the modeling of bullheading with applied boundary conditions and followed by mesh independence study for convergence analysis. Lastly is the bullheading model simulation and parametric study is conducted. Figure 3.2 is the process flow chart to develop the bullheadin model.

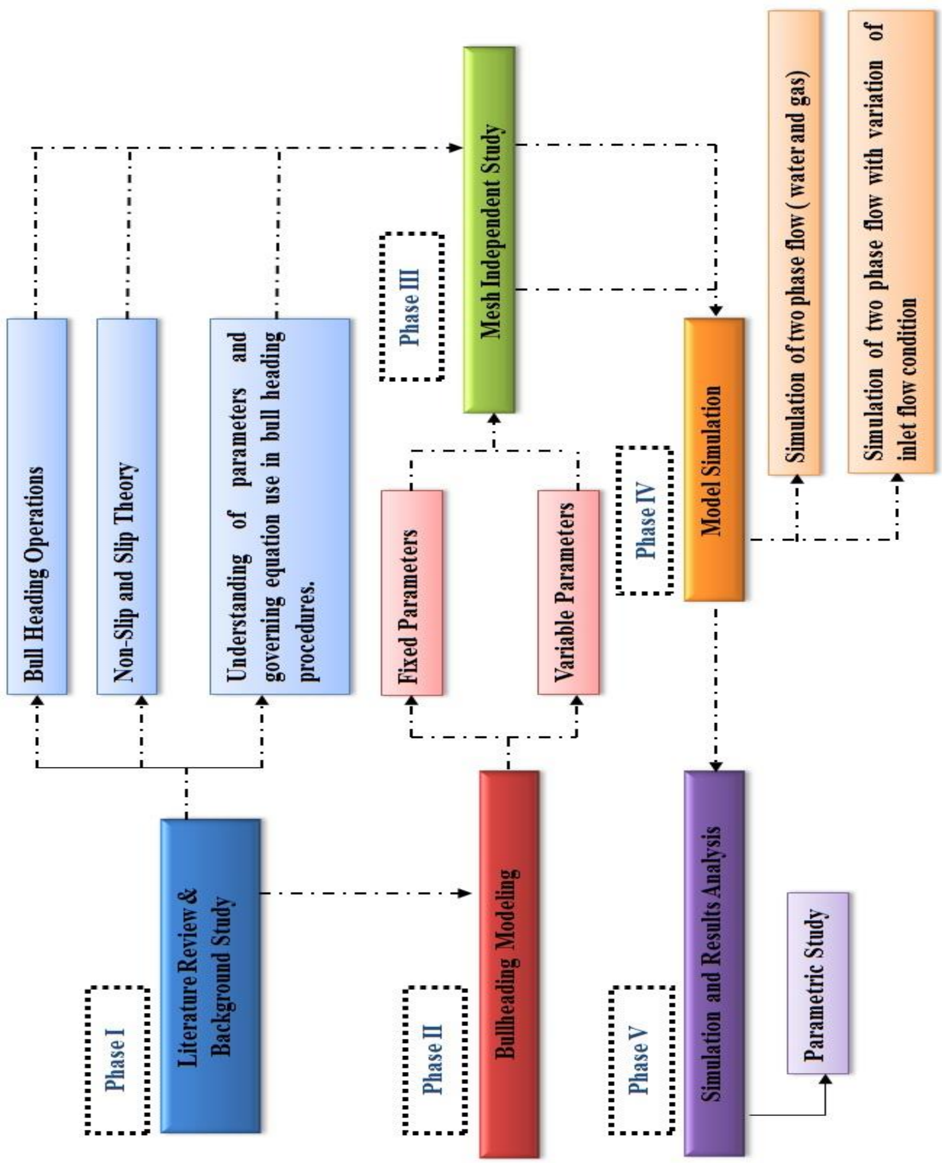


Figure 3.1 Five Phases of Project Methodology

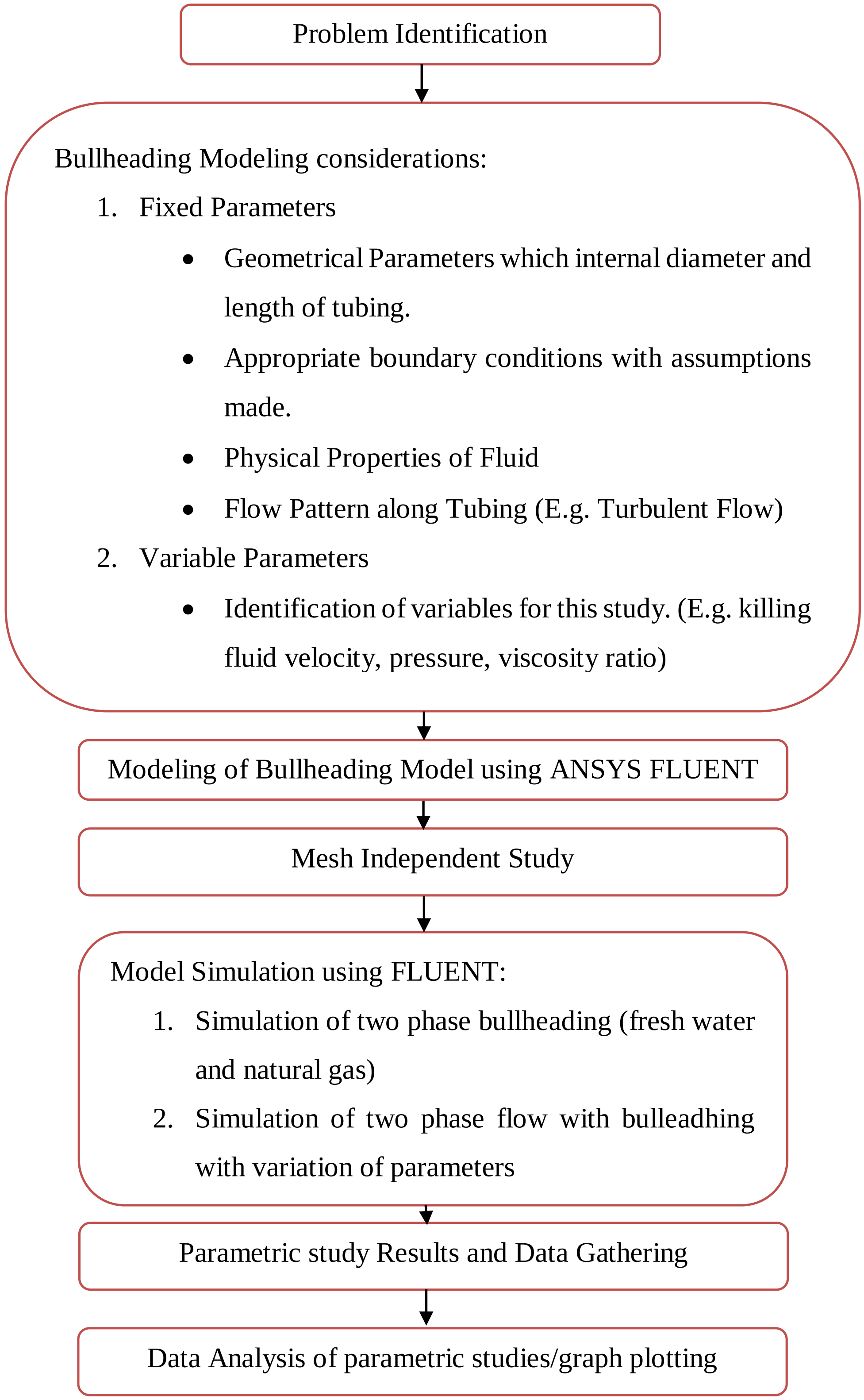


Figure 3.2 Bullheading Model Process Flow Chart

3.2 Development of model simulation

Numerical model simulation of Bullheading two-phase flow a definitive well kill is based on the schematic tubing in Figure 3.3 where it consist of the inlet (1) and outlet (2). Fine mesh is applied to the model and simulated by using CFD problem solver (ANSYS FLUENT). Parameter which is taken into high consideration is the inlet water velocity, pressure, viscosity and the frictional wall for tubing. The condition for gas inlet is held constant for all simulation.

The model applied for the simulation Eulerian Model in ANSYS FLUENT in modeling of two separate, yet interacting phases. In this research, continuity equations and the momentum balance equations are used as follows:

Continuity equation

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q\right) = 0 \tag{3.1}$$

Momentum Balance Equation

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \vec{v}_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right) = -\alpha_q \nabla p + \nabla.\bar{\bar{\tau}}_q + \alpha_q \rho_q \vec{g} + \sum_{p=1}^{n}(\vec{R}_{pq} \dot{m}_{pq} \vec{v}_{pq} - \dot{m}_{pq} \vec{v}_{qp}) + (\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}) \tag{3.2}$$

where q and p represent any two phases, $\vec{v} =$ velocity, α = volume fraction, ρ = density, p = pressure shared by all phases, $\vec{v}_{qp}$= inter-phase velocity, $\vec{g}$ = gravitational acceleration, $\vec{F}_q$= external body force, $\vec{F}_{lift,q}$= lift force, $\vec{F}_{vm,q}$ = virtual mass force, $\vec{R}_{pq}$= interaction force between phase and $\dot{m}_{pq}$= mass transfer from pth to qth phase.

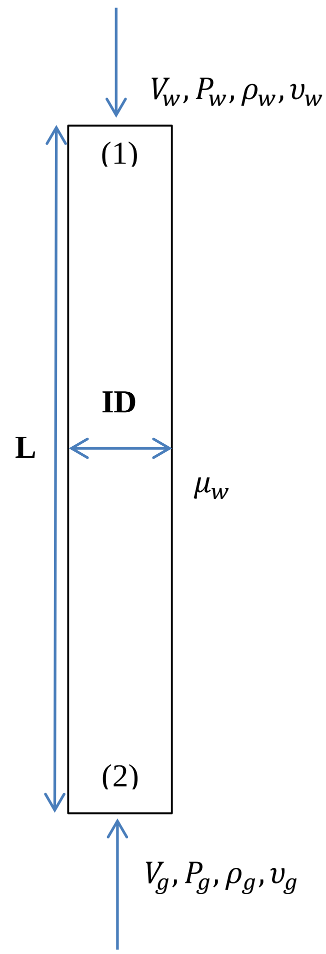


Figure 3.3 Schematic tubing with applied inlet and outlet boundary conditions

Table 3.1 illustrates the input parameters for variable paramaters and Table 3.2 is the fixed parameters applied in this study. The lowest and highest limit range for parametric studies have been set and listed in Table 3.1 to provide a clear view on how the parameters above affect the volume fraction water and pressure drop of tubing

Table 3.1 Variable Parameters for parametric studies

Variable Parameters	**Base Case**
Friction Wall of Tubing, μ_w	0.2 to 1.0
Velocity of Killing Fluid, V_k	2.0m/s to 10.0m/s
Pressure of Killing Fluid, P_k	4.0MPa to 8.0MPa
Viscosity ratio, υ_r	0.1 to 0.5

Table 3.2 Fixed Parameters for parametric studies

Fixed Parameters	Base Case
Length of Tubing, L	50 in
Internal Diameter of Tubing, ID	4 in
Density of Killing Fluid, ρ_k	998.2 kg/m³
Velocity of Gas, V_g	1.5m/s
Pressure of Gas, P_g	2.7MPa
Viscosity of Gas, υ_g	0.000007 kg/m-s
Density of Gas, ρ_g	9.4 kg/ m³

3.3 Model Meshing

When the model is finished developed, mesh is applied to the model before running the simulation. A fine mesh is essential to obtained more accuracy in simulation result. For bullheading study, the model is mesh using mesh size of 0.0001m². Figure 3.3 shows the meshing result of base case for present study.

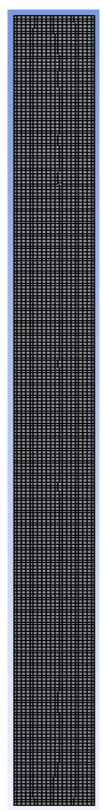


Figure 3.4 Model Meshing Results

3.4 Mesh Independent Analysis

This analysis is used to study the mesh dependent convergence behaviour. In order to study the convergence behaviour, several runs of simulation had been performed with varying size of element size. The pressure drop per unit length in the tubing is the criteria selected to check on the convergence behaviour. Figure 3.5 shown is the computational mesh of two different tubing with different element size.

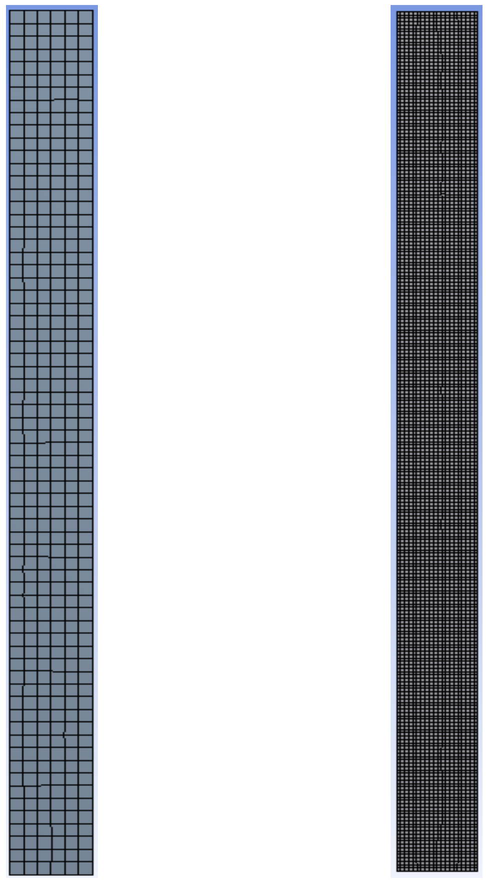


Figure 3.5 Comparison between large and small size of computational mesh of tubing

While Figure 3.6 illustrates the convergence behaviour of different mesh size based on the pressure drop per unit length obtained in the tubing. For the coarser meshes or smaller mesh size, the pressure drop per unit length values are varying between 3.0 kPa/in to 4.0 kPa/in. In other words, the error on the coarser mesh is high and it is mainly influenced by the mesh size. The curve converges when mesh is refined to smaller than 0.001mm^2 and it provides much better resolution compared to a bigger size mesh.

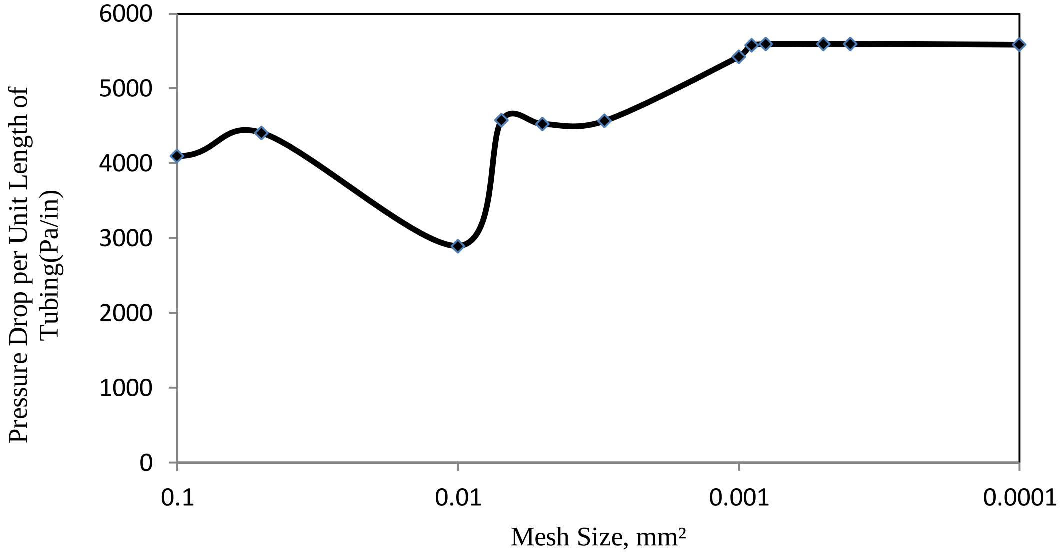
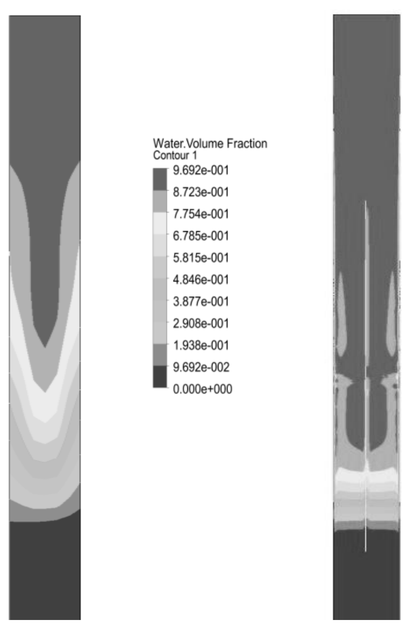


Figure 3.6 Pressure drop per unit length convergence versus mesh size

Figure 3.7 below illustrate the contours of the volume fraction of water in the tubing. Basically, the comparison is made between the coarsest mesh and the finest mesh which have cells size of 0.01mm² and 0.0001mm². It is shown that the contours differ from the coarsest and the finest meshes. Smaller mesh size of mesh show more accurate and precise contours compared to lager mesh size.



(a) 0.01mm² (b) 0.0001mm²

Figure 3.7 Volume fraction of water contour in tubing for 0.01mm² and 0.001mm² mesh size

3.5 Gantt Chart and Key Milestone

Below Table 3.3 Gantt chart is the representation of the activities in the research methodology to complete the simulation for two phase bullheading simulation in this research. The chart includes the time frame for Final Year Project I and Final Year Project II together with the key milestone which to be accomplished.

Item/Week	FYP I														FYP II													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of FYP Topic																												
Background Study & Literature Review																												
Exploring of ANSYS FLUENT																												
Development of Pre Bull Heading Simulation																												
Data Gathering and Selection of Parameters																												
Simulation of Bullheading Model and Parametric Study																												
Data Evaluation and Analysis																												
Presentation and Thesis Report																												

Table 3.3 Gantt Chart for FYP I and FYP II

3.6 Tools Required

The software used to simulate the bullheading model in this research is using ANSYS Fluent. ANSYS Fluent contains broad physical modeling capabilities which may assist in two phase flow simulation. It is ideally suited for both incompressible and compressible fluid-flow simulations. This software is also able to provide complete mesh flexibility including the ability to solve flow problems.

CHAPTER 4

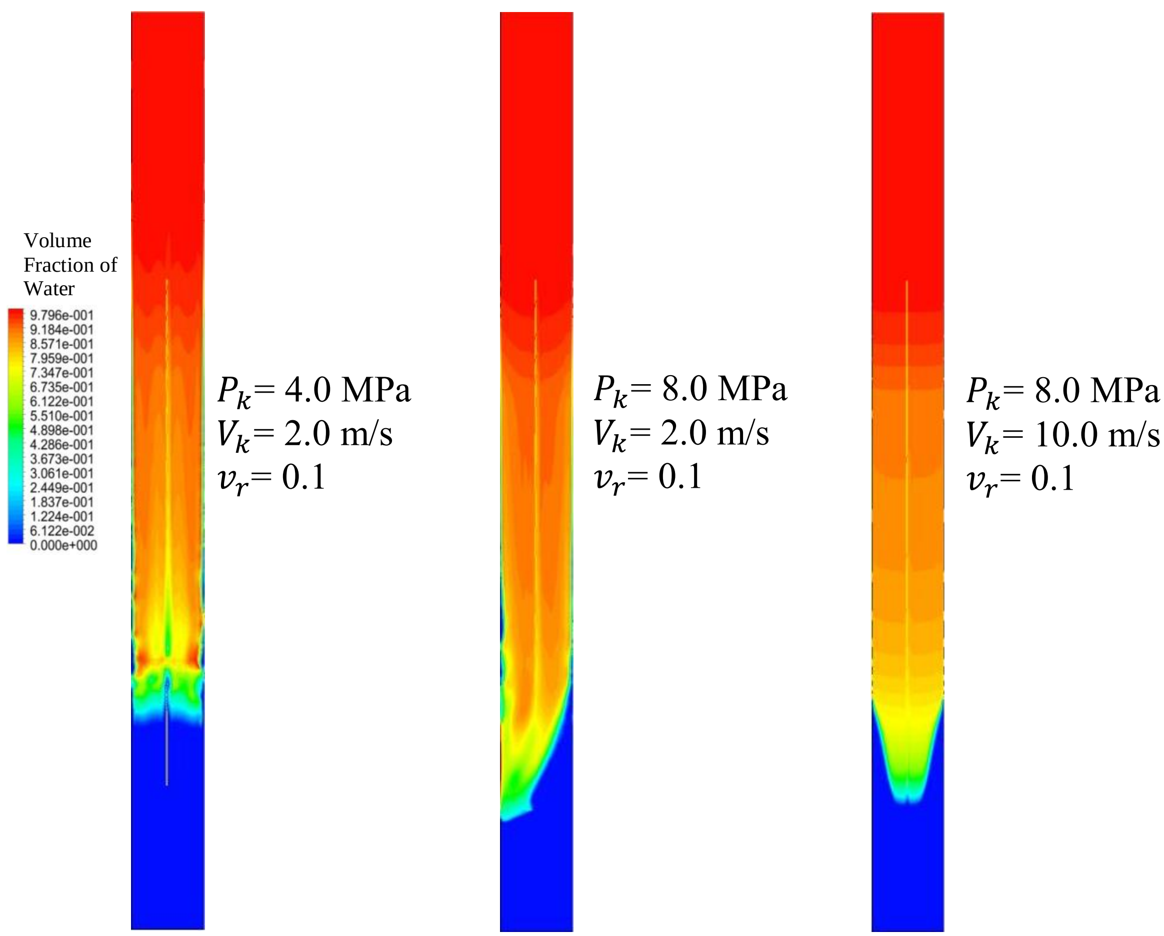
RESULTS & DISCUSSION

4.1 Parametric Studies for Bullheading Operation in Vertical Well

By using the simulation model that has been developed, 4 factors are being examined to determine the factors affecting bullheading operation through several parametric studies. Those variables are killing fluid pressure, velocity, viscosity ratio and friction wall of tubing. Detailed parameters of simulation model are summarized in Table 3.1 and 3.2 under Methodology chapter.

With the listed parameters range, the resulting volume fraction and pressure drop of water are shown as figures below according to the variation of input parameters. Below Figure 4.2 shows the interaction of fresh water and natural gas having with different parameters applied.

4.2 Results Visualization of Bullheading Simulation



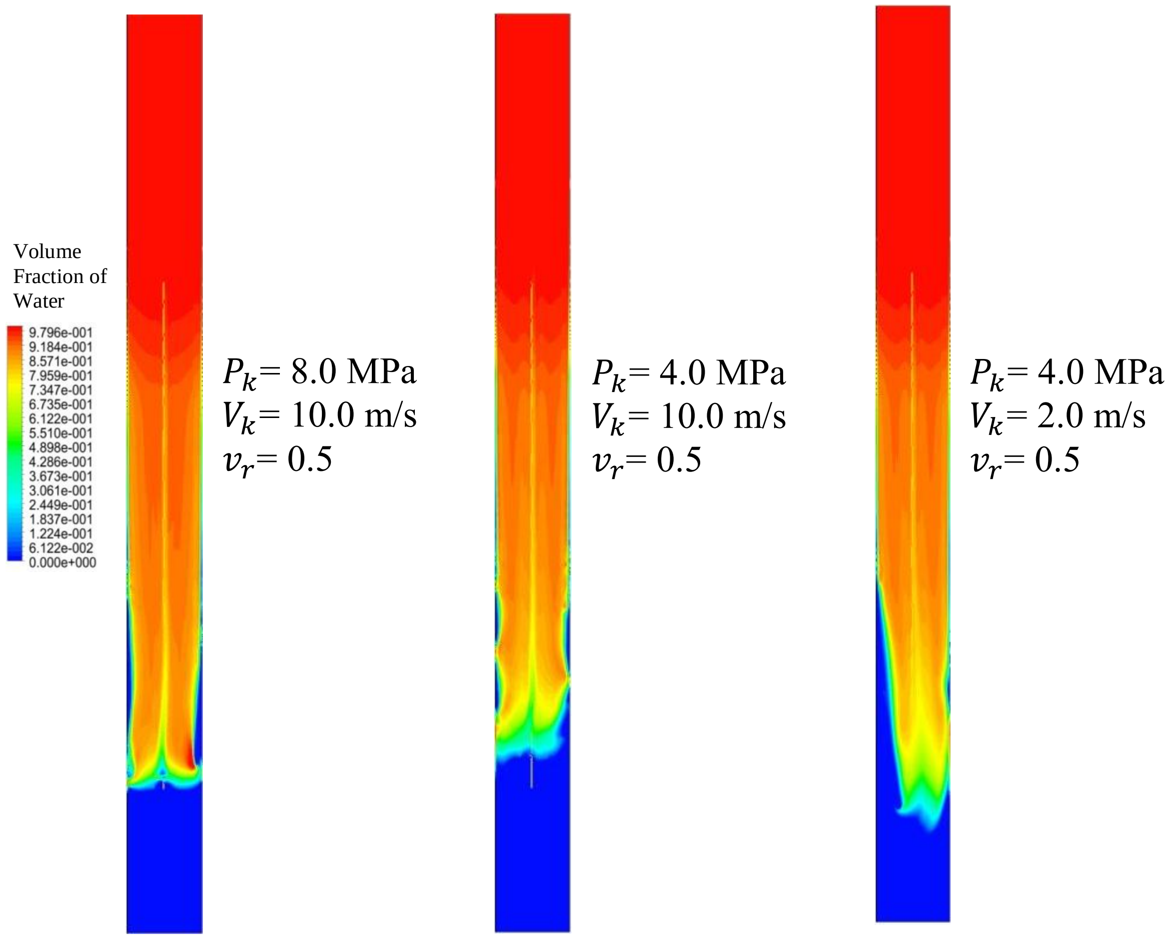
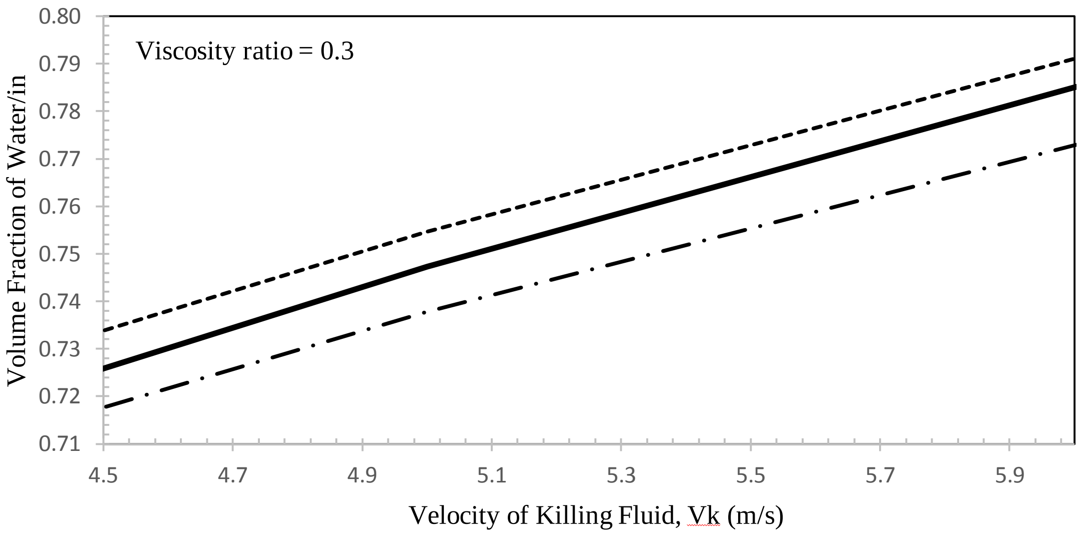


Figure 4.2 Results bullheading simulation with varying killing fluid pressure (P_k), velocity (V_k) and viscosity ratio (v_r)

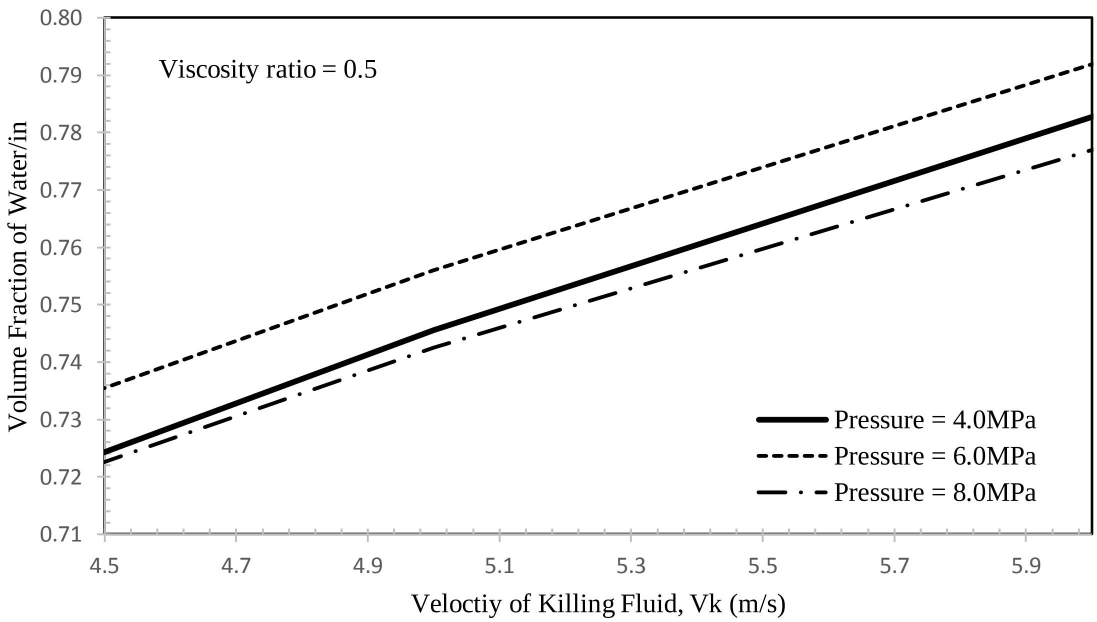
Density of Water, ρ_w = 998.2 kg/m³ and Friction Wall of Tubing, μ_w = 0.6

Figure 4.2 above shows the different interaction of fresh water and natural gas at t = 0.5s in terms of the volume fraction of water. For this cases, the frictional wall and the density for both fluids is held constant. Therefore, each of the factors stated affect the overall bullheading simulation. The effect of each factor on the volume fraction and pressure drop of water is analyzed in order to study the bullheading operation.

4.3 Volume fraction of water



(a)



(b)

Figure 4.3 Volume fraction of water based on velocity of killing fluid with varies in pressure of killing fluid and viscosity ratio with friction wall friction 0.6 and density of fresh water of 998.2 kg/m²

In Figure 4.3, the line for each section refers to the volume fraction of water per unit length with change of velocity of killing fluid. The change of volume fraction of killing fluid is measured having the minimum and maximum value as summarize as Table 4.1.

Table 4.1 Volume fraction of water per unit length with change of velocity of killing fluid, v_k

Pressure of Killing Fluid P_k (MPa)	Velocity of Killing Fluid, V_k (m/s)	Volume Fraction of Water					
		υ = 0.1		υ = 0.3		υ = 0.5	
		Min	Max	Min	Max	Min	Max
4.0	4.5 to 6.0	0.731	0.813	0.704	0.785	0.702	0.783
6.0		0.737	0.816	0.712	0.791	0.714	0.792
8.0		0.718	0.795	0.697	0.772	0.703	0.777

Figures 4.3 (a) and (b) analyze the effect of velocity of killing fluid in m/s, pressure of killing fluid in MPa and viscosity ratio on volume fraction of water for bullheading operation. Based on figure 4.3(a), the graph shows the volume fraction of water will increase rapidly as the velocity of the killing fluid increases. In terms of pressure of the killing fluid, as the pressure increases from 4.0MPa to 6.0MPa, the volume fraction of water increases slightly. However, at higher pressure of killing fluid applied, the volume fraction of water will reduces.

Comparing graphs (a) and (b), as the viscosity ratio increases from 0.3 to 0.5, the volume fraction of water will increase. However, when the pressure of the killing fluid is 4.0MPa the volume fraction of water reduces as can be observe the trend in the above figures.

In conclusion, volume fraction of water is directly proportional to velocity of killing fluid. Besides that, it can be conclude that at higher pressure of killing fluid with low viscosity ratio, the volume fraction will increase, whereas at low pressure of killing fluid with higher viscosity ratio, it results in the decreases of volume fraction water.

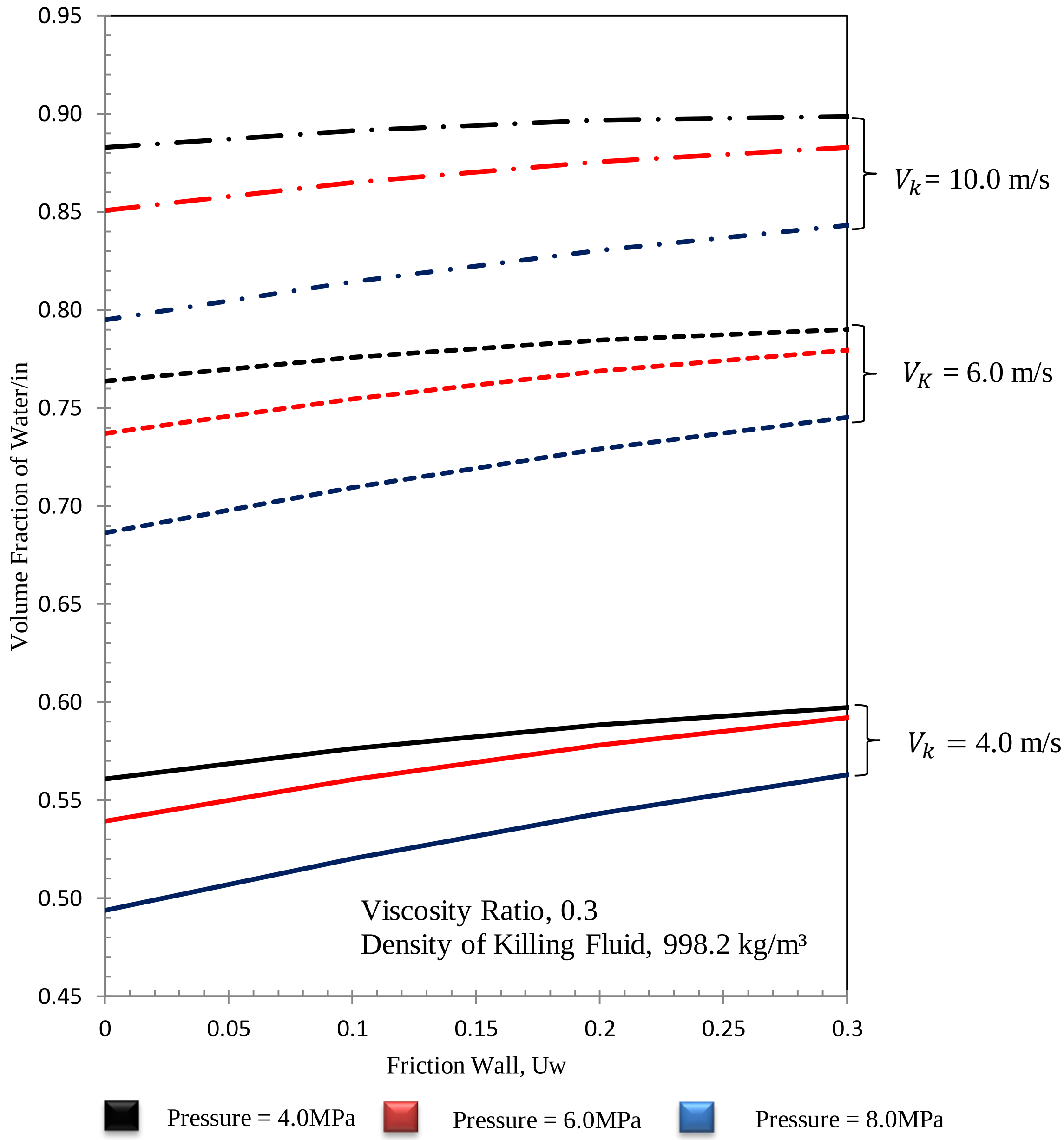


Figure 4.4 Volume fraction of water based on friction wall of tubing with varies of pressure of killing fluid 4.0, 6.0 and 8.0 MPa and velocity of killing fluid

In Figure 4.4, the line for each section refers to the volume fraction of water per unit length with change of friction wall of tubing with velocity of killing fluid of 2.0 m/s, 6.0 m/s and 10.0m/s with variation of pressure of killing fluid is summarized as Table 4.2.

Table 4.2 Volume fraction of water per unit length with change of friction wall, μ_w

Velocity of Killing Fluid, V_k (m/s)	Friction Wall of Tubing, μ_w	Volume Fraction of Water					
		P=4.0MPa		P = 6.0MPa		P = 8MPa	
		Min	Max	Min	Max	Min	Max
2.0	0.0 to 0.30	0.560	0.597	0.540	0.592	0.494	0.563
6.0		0.764	0.790	0.737	0.780	0.686	0.745
10.0		0.882	0.899	0.851	0.883	0.795	0.843

Based on Figure 4.4, it shows that the volume fraction of water increases as the friction wall increases. In the figure, it also explained that when velocity of increases, it also results in increases of volume fraction of water. Comparing the lines for velocity of killing fluids is 2.0 m/s, 6.0 m/s and 10.0 m/s, as the value of pressure of killing fluid increases from 4.0 MPa to 8.0 MPa, the volume fraction of water also are decreases. Furthermore, by observing the trend of lines, it is shown that when the velocity of killing fluid is 10.0 m/s, the changes of the volume fraction are very small as shown as the friction wall increases.

In conclusion, the volume fraction of water is directly proportional to friction wall of tubing. The volume fraction of water is inversely proportional to pressure of the killing fluid as friction wall of tubing increases. However, the effect of increasing friction wall of the tubing to the volume fraction of water is small.

From the parametric studies above, Figure 4.5 summarizes the influence of four parameters in percentage upon the volume fraction of water. It illustrates that the velocity of killing fluid, v_k does the most impact on the volume fraction of water, and then followed by the viscosity ratio, v_r and pressure of the killing fluid, p_k respectively. However, in this case, friction wall, μ_w have the least impact or does not contribute to the volume fraction of water compared to the other three parameters.

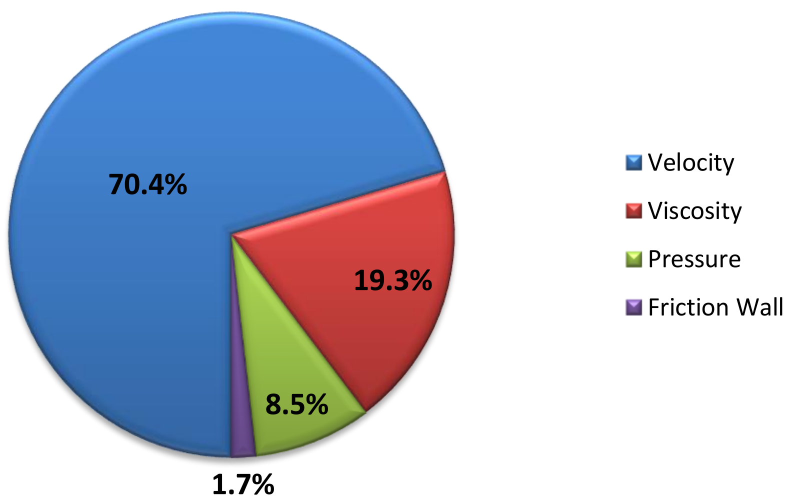


Figure 4.5 Parameter Weighting Factors based on volume fraction of water

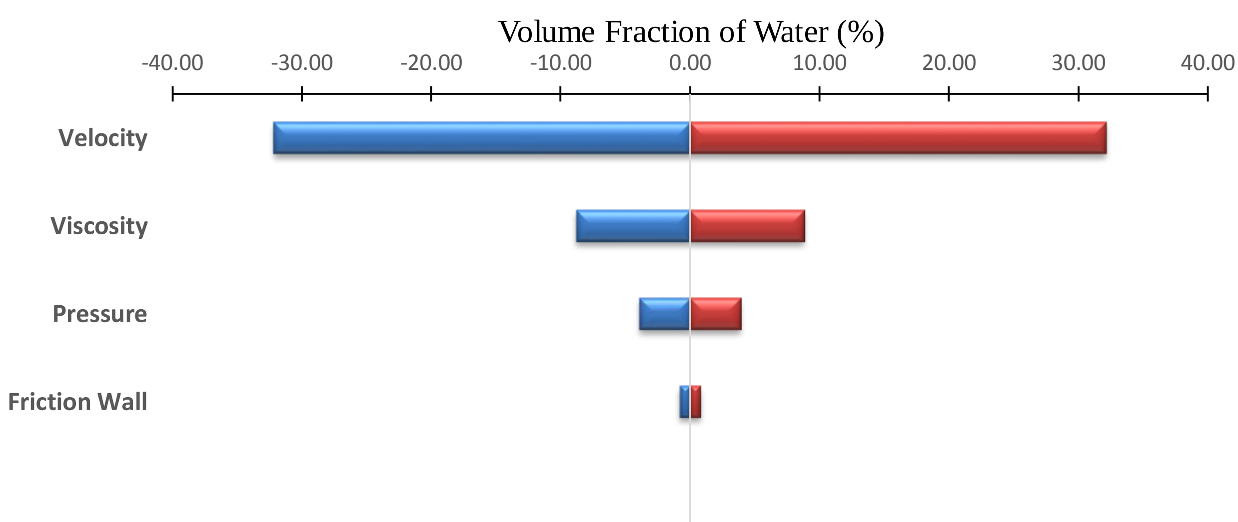


Figure 4.6 Parameters' sensitivity to volume fraction of water

In terms of parameters' sensitivity, tornado chart is constructed as shown in Figure 4.6. This chart clearly illustrates the sensitivity of parameters to the solution. It explained that the most sensitive parameters are the velocity of killing fluid and viscosity ratio where all of these factors have the affecting percentage more than 10% out of the 4 parameters. The pressure of killing fluid giving sensitivity less than 10% while the least sensitivity is the friction wall which is less than 5%.

4.4 Pressure Drop in Tubing

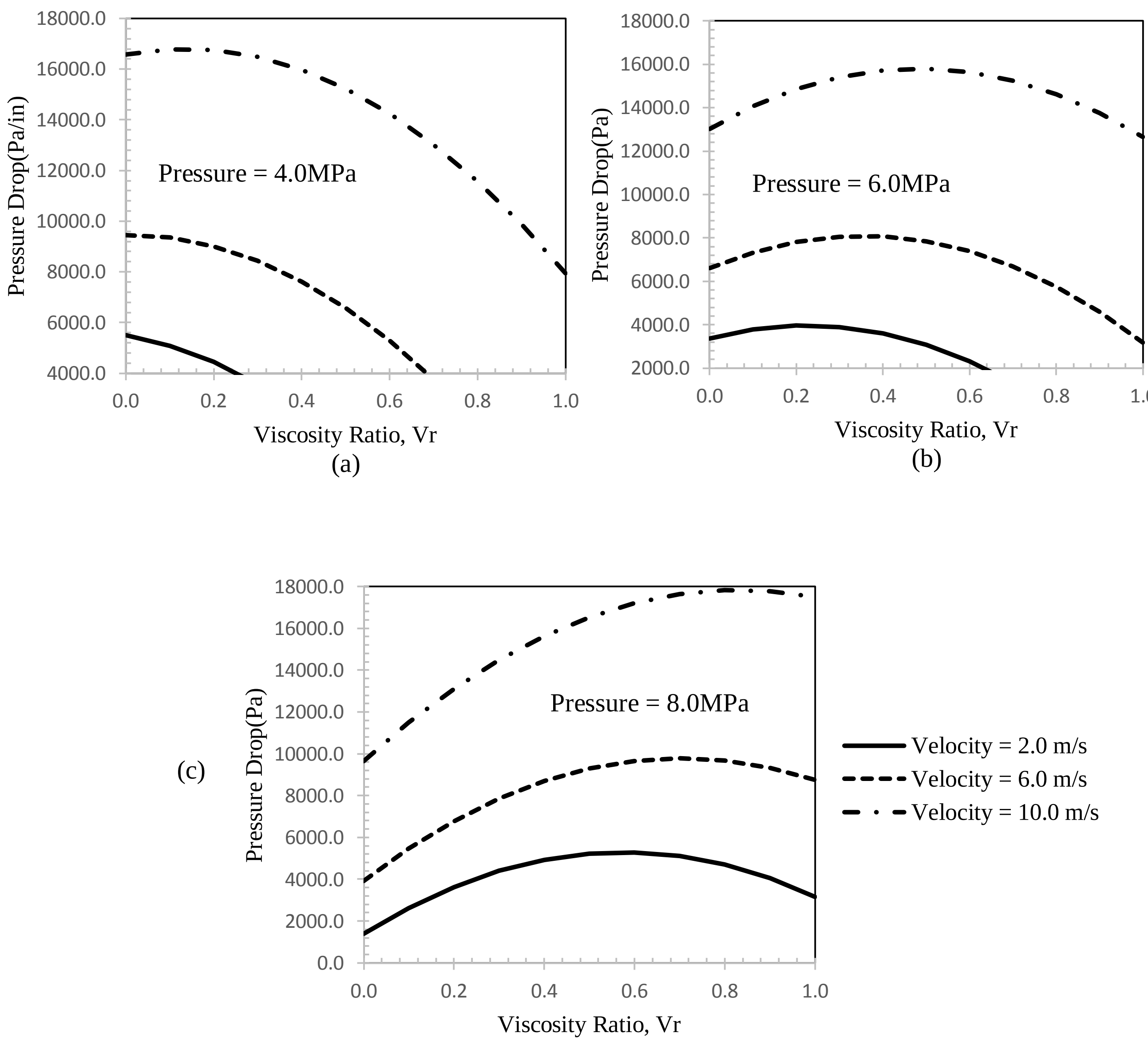


Figure 4.7 Pressure drop based on the viscosity ratio with variation of velocity of killing fluid with friction wall 0.6 and density of water 998.2 kg/m³

In Figure 4.7, the line for each section refers to the pressure drop per unit length with change of viscosity ratio with variation of velocity of killing fluid and pressure of killing fluid. The change of volume fraction of killing fluid is measured having the minimum and maximum value as summarize as Table 4.3.

Table 4.3 Pressure drop per unit length with change of viscosity ratio, υ_r

Velocity of Killing Fluid, V_k (m/s)	Viscosity Ratio, υ_r	Pressure Drop(Pa)		
		P = 4.0MPa	P = 6.0MPa	P=8.0MPa
		Max	Max	Max
2.0	2.0 to 8.0	5498.5	3359.6	5287.1
6.0		9455.6	6609.0	9782.4
10.0		16586.2	15792.1	17823.4

Figures 4.7 (a), (b) and (c) analyze the effect of viscosity ratio, pressure of killing fluid in MPa and viscosity ratio on pressure drop in tubing for bullheading operation. Based on Figure 4.7(a), the graphs shows the pressure drop in tubing increases as the viscosity ratio increases, however at a certain viscosity ratio the pressure drop start to decrease. The graph shows it has the maximum value of pressure drop. The maximum pressure drop in tubing varies with the value of velocity of killing fluid as shown in Table 4.3. The situation differs in Figure 4.7 (a) and (b) and (c) as the pressure of killing fluid increases. Comparing all figures in Figure 4.7, as the pressure of the killing fluid increases, the maximum pressure drop of tubing are increase except for figure 4.7 (a) and (b) which the maximum value are almost equal. However, the maximum pressure drop occurs at different viscosity ratio. As for Figure 4.7 (c), the maximum pressure drop occurs at higher viscosity ratio. Therefore, at low pressure of killing fluid, the maximum pressure drop occurs at low viscosity ratio, however, when the pressure applied is increase, the pressure drop are also increase with maximum pressure drop at high viscosity ratio.

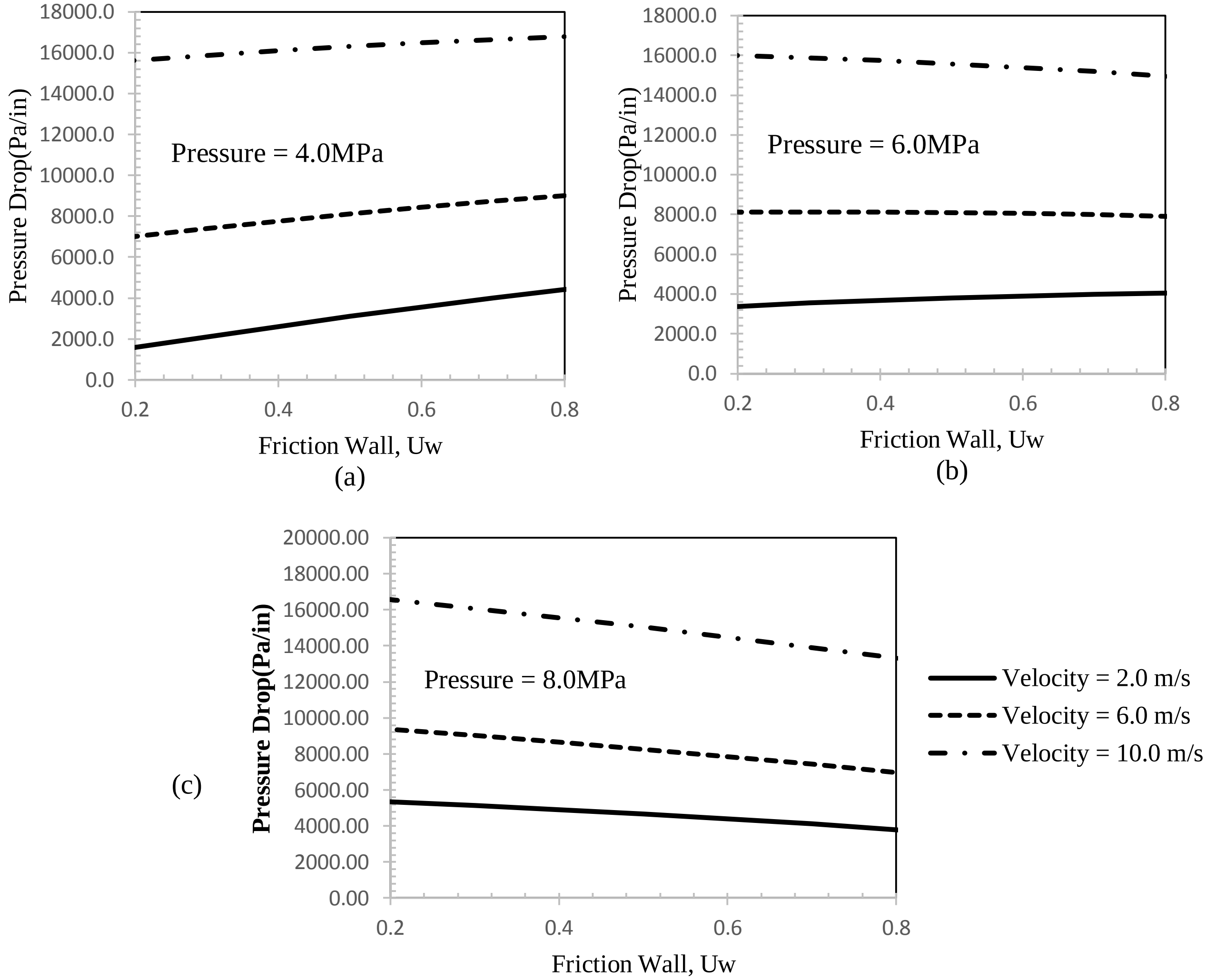


Figure 4.8 Pressure drop based on the friction wall with variation of velocity of killing fluid and pressure of killing fluid with friction wall 0.6 and density of water 998.2 kg/m³

Based on Figure 4.8, the line for each section refers to the pressure drop of water per length with change of friction wall of tubing with velocity of killing fluid of 2.0 m/s, 6.0 m/s and 10.0m/s with variation of pressure of killing fluid is summarized as Table 4.4.

Table 4.4 Pressure drop per unit length with change of friction wall of tubing, μ_w

Velocity of Killing Fluid, V_k (m/s)	Friction Wall, μ_w	Pressure Drop(Pa)					
		P = 4.0MPa		P = 6.0MPa		P=8.0MPa	
		Min	Max	Min	Max	Min	Max
2.0	0.2 to 0.8	1579.6	4430.4	3380.1	4033.8	3800.4	5344.0
6.0		7015.4	9017.0	7912.8	8108.3	6971.7	9364.4
10.0		15624.5	16777.1	14965.1	16009.8	13316.2	16558.2

Based on Figure 4.8 (a), it shows that the pressure drop increases when the friction wall increases. The graph also explained that when the velocity of killing fluid increases, it also results in increases of pressure drop.

As shown in above Figure 4.8, graph (a), (b) and (c), the results of the pressure drop differ as the pressure of killing fluid increases. Looking at Figure 4.8(b), the pressure drop starts to reduce when the velocity of the killing fluid are increase when pressure of killing fluid increases from 4.0MPa to 6.0MPa as the friction wall increase. In Figure 4.8(c), it shows that the further increase in pressure of killing fluid, it will cause the pressure drop in tubing to decreases.

In conclusion, the pressure drop is directly proportional to friction wall of tubing at low pressure, however, the situation changes where pressure drop is inversely proportional to the friction wall with higher pressure applied.

From the parametric studies above, Figure 4.9 summarizes the influence of four parameters in percentage upon the pressure drop. It illustrates that the viscosity ratio, v_r does the most impact on the pressure drop, and then followed by the velocity of killing fluid, v_k and friction wall, μ_w respectively. However, in this case, pressure of killing fluid, P_k have the least impact or does not contribute in pressure drop compared to the other three parameters.

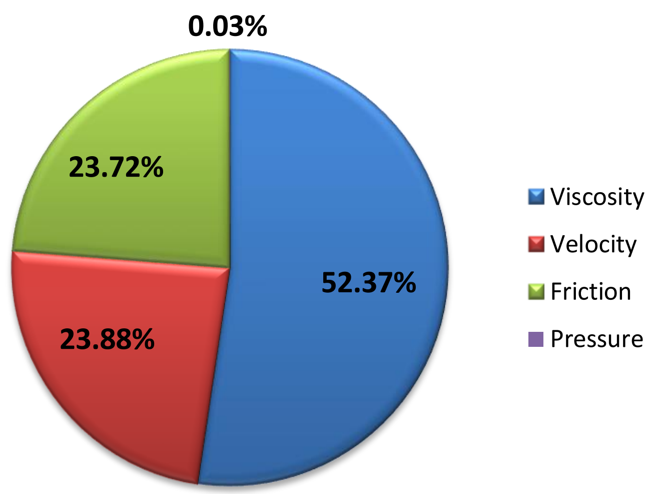


Figure 4.9 Parameter Weighting Factors based on of pressure drop

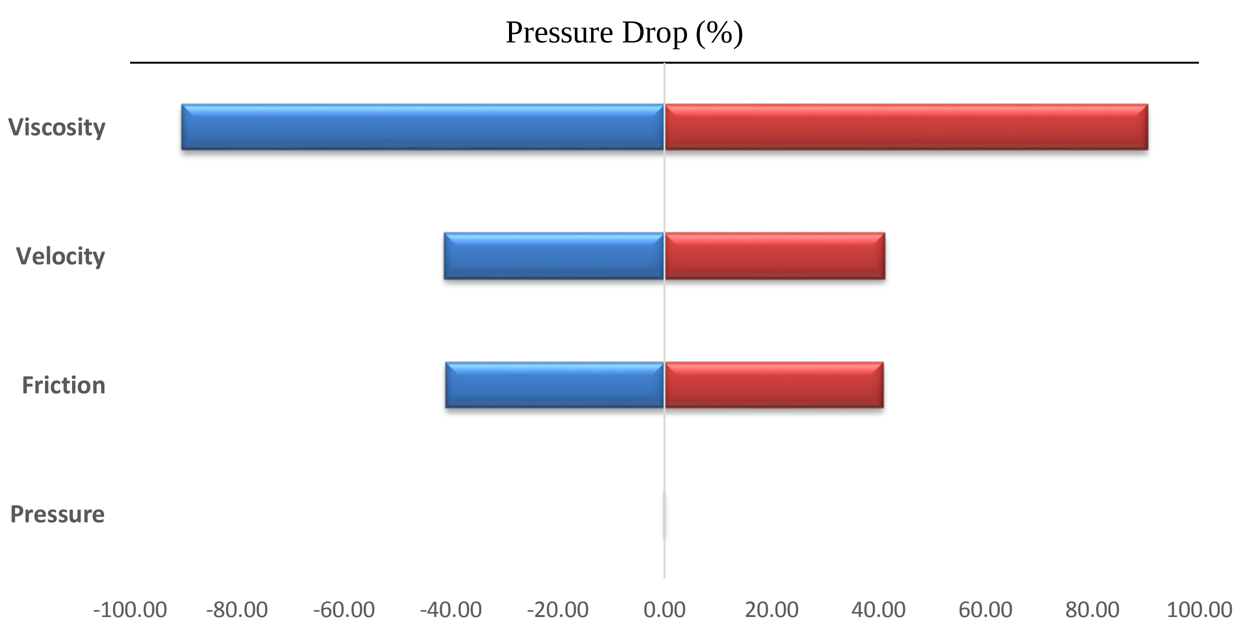


Figure 4.10 Parameters' sensitivity to pressure drop

In terms of parameters' sensitivity, tornado chart is constructed as shown in Figure 4.10. This chart clearly illustrates the sensitivity of parameters to the solution. It explained that the most sensitive parameters are the viscosity ratio where all of these factors have the affecting percentage more than 80% out of the 4 parameters. While velocity of killing fluid and friction wall of tubing give almost the same equal sensitivity which is around 40%. The least sensitive parameters is the pressure of the killing fluid having less than 1%.

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

In this study, the factors affecting bullheading procedure is determined which is the killing fluid pressure, velocity, viscosity ratio and friction wall of tubing. The contribution of all the factors has been measured from the two outcomes which is the volume fraction of water and pressure drop in the tubing**.**

This research has concluded that, in volume fraction of water, the most contributing factors are velocity of killing and viscosity ratio while pressure of killing fluid does not contribute much. In fact, friction wall does not make any significant in volume fraction of water in bullheading. For pressure drop of tubing, the most contributing factors are viscosity ratio while velocity of killing fluid and friction wall of tubing give lesser contribution in bullheading. The four factors affecting volume fraction of water and pressure drop has their individual role, however velocity of killing fluid and viscosity ratio are the two factors highest contributors on both cases. Therefore, in initiating bullheading, these two factors should be highly take into consideration for successful well kill.

Bullheading is one of the well control in petroleum industry plays a big role in preventing blowout by killing the well. Therefore, in further research on bullheading is important since there is less information which is available in this area. This study can be enhancing more by including the analyzing of formation condition. Besides that, the type of killing fluid and type of well can be considered as one of the factors affecting bullheading. Lastly, detail study can be conducted on the interaction of fluids since it is fluid circulation is difficult to be control and predicted.

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APPENDIX

SETUP OF BULLHEADING MODEL

Solver	***Input***
Type	Pressure-Based
Time	Transient
Velocity Formulation	Absolute
2D Space	Planar
Gravitational Acceleration	$-9.81\ ms^{-2}$
Models	
Multiphase	Eulerian (2 Eulerian Phases, Volume Fraction Parameters: Implicit
Viscous	K-epsilon (Turbelence)
Materials	
Fluid	Water-Liquid Properties : a. Density : 998.2 kg/m3 Viscosity : 0.001003 kg/m-s
	Gasoil-Vapor Properties: a. Density : 9.4 kg/m3 b. Visocity: 7e-06 kg/m-s
Phases	***Input***
Primary Phase	Water-Liquid
Secondary Phase	Gasoil-Vapor

Boundary Condition	***Input***
Inlet	i. Phase: Mixture Type : Velocity-Inlet Supersonic/Initial Gauge Pressure : 4 MPa Turbulence : a. Specification Method : K and Epsilon b. Turbulent Kinetic Energy : 1 m2/s2 c. Turbulent Dissipation Rate : 1m2/s3 ii. Phase : Water-Liquid Type: Velocity Inlet Momentum : a. Velocity Specification Method : Magnitude, Normal to Boundary b. Reference Frame : Absolute c. Velocity Magnitude : 2 m/s iii. Phase : Gasoil-Vapor Type: Velocity Inlet Momentum : a. Velocity Specification Method : Magnitude, Normal to Boundary b. Reference Frame : Absolute c. Velocity Magnitude : 0.5 m/s Multiphase : a. Volume Fraction of Air : 0.05
Outlet	iv. Phase: Mixture Type : Velocity-Inlet Supersonic/Initial Gauge Pressure : 2.7 MPa Turbulence : a. Specification Method : K and Epsilon b. Turbulent Kinetic Energy : 1 m2/s2

	c. Turbulent Dissipation Rate : 1m2/s3 v. Phase : Water-Liquid Type: Velocity Inlet Momentum : d. Velocity Specification Method : Magnitude, Normal to Boundary e. Reference Frame : Absolute f. Velocity Magnitude : 0 m/s vi. Phase : Gasoil-Vapor Type: Velocity Inlet Momentum : d. Velocity Specification Method : Magnitude, Normal to Boundary e. Reference Frame : Absolute f. Velocity Magnitude : 1.5 m/s Multiphase : b. Volume Fraction of Air : 1.00
Operating Condition	
Operating Pressure	101325 Pa
Variable-Density Parameters	Specified Operating Density : None
Solution Method	
Pressure-Velocity Coupling	Scheme : Coupled
Spatial Discretization	Gradient : Least Squares Cell Based Momentum: First Order Upwind Volume Fraction : First Order Upwind Turbulent Kinetic Energy : First Order Upwind Turbulent Dissipation Rate : First Order Upwind
Transient Formulation	First Order Implicit

Solution Control	
Flow Courant Number	200
Explicit Relaxation Factors	Momentum : 0.75 Pressure : 0.75
Under-Relaxation Factors	Density: 1 Body Forces : 1 Volume Fraction : 0.5 Turbulent Kinetic Energy: 0.8 Turbulent Dissipation Rate: 0.8
Solution Initialization	
Initialization Methods	Standard Initialization
Compute from	Inlet
Reference Frame	Relative to Cell Zone
Initial Values	Gauge Pressure : 4000003 Pa Turbulent Kinetic Energy : 1 m2/s2 Turbulent Dissipation Rate : 1 m2/s3 Water x-velocity : 0 m/s Water y-velocity : -2 m/s Gas x-velocity : 0 m/s
Calculation Activities	
Contour	Pressure : Total Pressure Phases : Volume Fraction
Run Calculation	
Time Stepped Method	Time Step Size (s) : 0.1
Number of Time Steps	30
Max Iterations/Time Step	100